4. Ultraviolet Science

Although HST has achieved its long-heralded promise in the areas of high-resolution optical imaging and UV spectroscopy, its unique UV imaging capabilities have not yet been fully exploited mostly because of technical limitations. The low throughput, red leaks, and/or small fields of the UV imagers on HST to date have prevented users from exploiting quantitative UV imaging despite its great scientific potential. The UV spectral region is rich in information on the astrophysical properties of solar system objects, stars, star forming regions, and galaxies. The UV is, of course, uniquely sensitive to hot sources, in particular to the massive stars which are responsible for most "star-formation astrophysics," as well as to certain types of old, highly evolved, stars. This regime is also critical for studies of the metal abundances and surface gravities, two fundamental parameters of stellar astrophysics. Thus, the UV is the spectral region of choice for studies of the star formation and chemical enrichment histories of stellar systems, both in our own galaxy and others.

There are also many key diagnostics of interstellar gas and dust in the region below 4000 Å, including the 2175 Å peak in the dust extinction law, and a number of important emission lines such as the astrophysical plasma diagnostic emission line [O II] 3727 Å. However, neither STIS nor ACS offer good sensitivity over wide fields in the 2000-4000 Å spectral region.

For moderate and high-redshift objects ($z \geq 0.4$), the restframe far-UV (λ < 1500 Å) is redshifted into the 2000-4000 Å region in the observer's frame, making this a key probe of distant star-forming galaxies and active galactic nuclei (AGN). This near-UV region is particularly important in searching for galaxies in the $z \sim$ 1-2 redshift range, based on "Lyman-dropouts." It is at these redshifts that the star-formation rate in the Universe might peak, according to estimates from deep surveys. Ground-based telescopes have great difficulty sampling this redshift range because the Earth's atmosphere is opaque to wavelengths below 3000 Å. Furthermore, the region 1600-2500 Å is one of the darkest parts of the natural sky background above the Earth's atmosphere, permitting the detection of extremely faint sources.

The combination of a large set of optical/UV filters, high sensitivity, high spatial resolution, low readout noise, low dark current, and large field of view will allow HST WFC3 to address a number of key scientific questions for the first time. A few important examples are described below.

4.1 Stellar Archaeology

(a) Resolved Stellar Populations

The history of star formation in galaxies is recorded in the types, or "populations," of stars they contain. HST's superb spatial resolution and ability to measure the brightness of individual faint stars in star clusters and nearby galaxies (see Figure 5) have enabled enormous strides to be made in our understanding of stellar mass distributions, and star-formation histories within our own galaxy and nearby galaxies. WFC3 will significantly enhance the existing capabilities of HST in this area. Large, well-sampled fields of view are necessary to probe stellar populations in extended stellar systems. UV access is required for high-quality measures of stellar temperatures, metallicities, and surface gravities. For example, A and F type stars are particularly important for tracking metal enrichment, star formation histories, and galaxy disk evolution. The ability to obtain deep UV observations just shortward of the Balmer jump (3650 Å) provides an excellent estimator of surface gravities of these stars, thus providing information on their intrinsic luminosity.

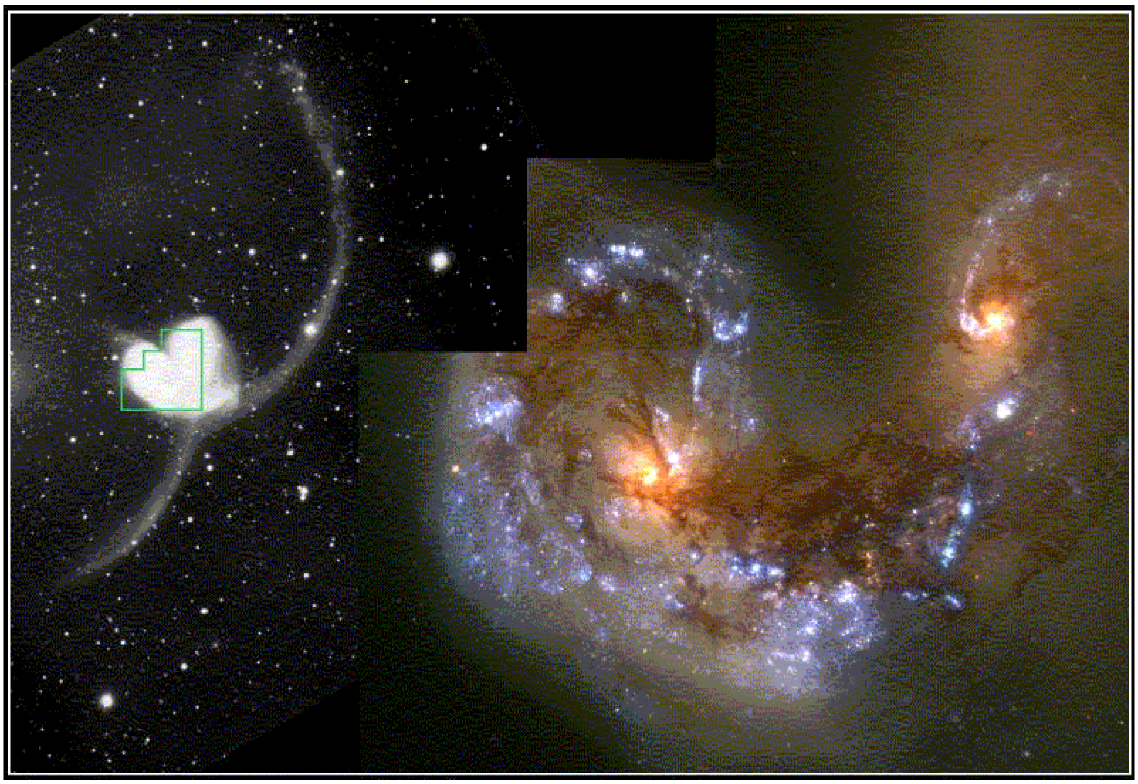

Figure 5. The Antennae Galaxies (NGC 4038/4039) imaged by WFPC2 (B. Whitmore and NASA). The image shows the richness of star-forming regions (rich in hot, young stars visible in blue) and dust lanes present in this merger of two spiral galaxies. The bulges of the merging spirals contain older, colder stars and are visible in red.

In older stellar populations (ages over 5 Gyr), helium-burning stars in advanced evolutionary phases have surface temperatures above 10000 K, making them UV-bright (see Figure 6). UV imaging by ASTRO/UIT and HST has recently opened up an entirely new window on this last under-explored corner of normal stellar evolution. These hot objects are not only important in their own right but also provide key information on mass loss during the red-giant-branch evolution which precedes the hot phases. Mass loss is a central problem in stellar astrophysics and is related to a number of other important processes, such as dust production, X-ray emission, and accretion flows in elliptical galaxies. We expect that the wide-field, near-UV capability of WFC3 will allow us to make rapid progress in increasing our understanding of advanced stellar evolution.

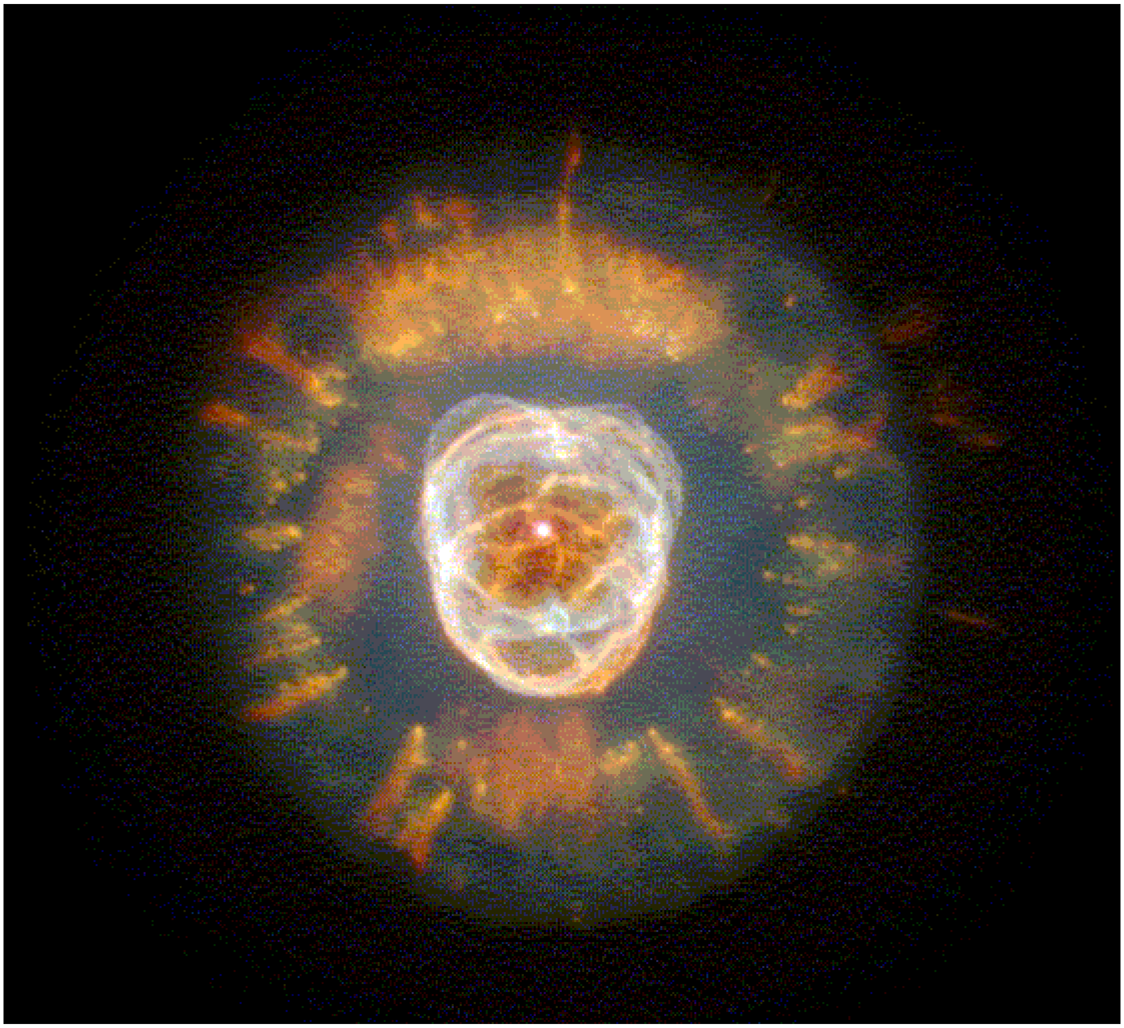

Figure 6. The Eskimo planetary nebula (NGC 2392) imaged by WFPC2 (A. Fruchter and NASA). The nuclei of planetary nebulae are old stars that have lost their outer layers and emit most of their light at UV wavelengths. This UV radiation ionizes the ejected material, producing the bright nebula.

(b) Stellar Populations in Integrated Light

For more distant galaxies, individual stars cannot be observed, but the constituent stellar populations can still be deduced from their integrated light. The ultraviolet sensitivity of WFC3 will be invaluable, since the ultraviolet has the highest sensitivity of any spectral region to stellar temperature and metal abundance. These are the types of parameters needed to deduce stellar populations, star-formation rates (SFR's), and star-formation histories. Figure 7 illustrates the strong evolution of the integrated UV energy distributions of stellar populations over timescales up to 3 Gyr. The spectra in the figure have been normalized at 5500 Å (the V band). The amplitude of the spectral change at 2000 Å is over 4 magnitudes larger (a factor 40 in flux) than the change at 10000 Å. Furthermore, the figure shows that the spectral line structure of the region shortward of 5000 Å contains a wealth of information which can be analyzed with narrow- and intermediateband filters. The high-sensitivity region begins below about 4000 Å, where the confluence of hydrogen absorption lines in hotter stars and the Balmer Jump and metallic absorption features in cooler ones begin to strongly affect the gross spectral structure.

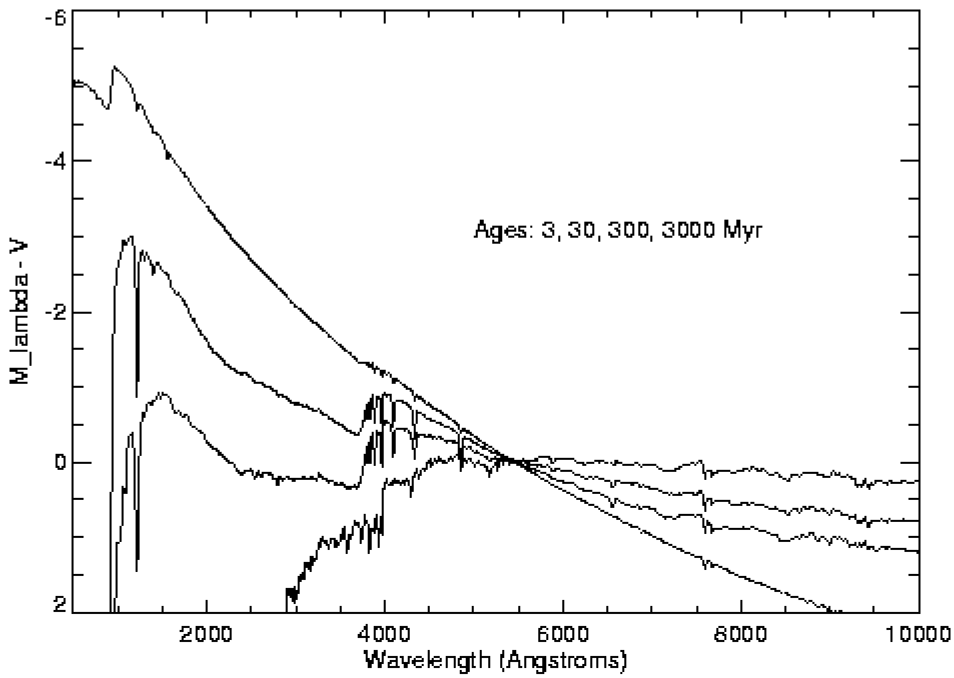

Figure 7. Theoretical model spectra of integrated stellar populations of various ages. We plot the magnitude as a function of wavelength normalized to the visible band. The spectra become redder with increasing age (G. Bruzual and S. Charlot 1996).

The UV allows *direct detection* of the massive stars responsible for most of the ionization, photo-dissociation, kinetic-energy input, and element synthesis in galaxies. These processes are responsible for much of the astrophysics of the universe. By contrast, most other methods of studying massive star populations yield only *indirect* measures since they rely on re-processing of the UV photons by the surrounding medium (H II regions or dust clouds). Furthermore, since the production of Lyman-continuum photons by young populations rapidly declines after □ 5-10 Myr, these other methods probe star formation only over a short period, which constitutes a tiny fraction (0.05%) of the lifetime of a galaxy. By comparison, the short-wavelength continuum below 4000 Å remains a sensitive indicator of star-formation histories for ages up to 100 times greater.

4.2 The Assembly of Galaxies at High Redshift

We now suspect that much of the "final assembly" of galaxies, and much of the conversion of primeval gas into stars, occurred at relatively low redshifts in the range z □ 1-3. These redshifts correspond to lookback times of half to three-quarters of the present age of the Universe. The most productive technique developed so far for identifying star-forming galaxies in this redshift range and greater is the “Lyman-dropout” method, which uses the fact that absorption from the ground state of neutral hydrogen produces a strong discontinuity in the restframe energy distribution below 912 Å. Unfortunately, the Lyman-dropout technique is not applicable to most of this redshift range, unless one has access to the observed wavelength interval 2000—3500 Å. The wide field and good near-UV sensitivity of WFC3 are ideally suited to the exploration of this critical early epoch.

WFC3's enhanced sensitivity over WFPC2 will permit identification of candidate sources in the more distant (z □ 3-5) range up to 2 magnitudes fainter than achieved in the Hubble Deep Fields. At present, our sample of these distant objects is limited to only the most luminous young galaxies. The WFC3 U and B band dropout sample – obtained by searching for galaxies lacking flux in the U- and the B-band, respectively, but which have relatively bright luminosities at longer wavelengths - would be a basic resource for spectroscopic campaigns by the NGST.

One can also exploit the hydrogen Lyman-alpha emission line (1216 Å in the rest frame), which has been found to be bright in many distant galaxies. This feature can be detected with narrow-band filters or prisms in the 2000-5000 Å range, covering redshifts z □ 0.8-3. Of special interest are the numerous “sub-galactic clumps,” which make up a significant part of the faint blue galaxy population. Through the process of repeated hierarchical merging, it is believed that these clumps came together to form the luminous galaxies we see today, i.e. they are the building blocks of galaxies. If they exist everywhere, they may be used to trace the large scale structure of the Universe. Hence the statistical and physical properties of these objects are essential in order to constrain theories of galaxy formation.

A final, more speculative possibility for WFC3 is the detection of very high redshift (z □ 10) systems with hard intrinsic extreme-UV energy distributions - redshifted into the 2000-4500 Å region. Absorption by the surrounding neutral hydrogen usually extinguishes sources in the restframe spectral region between □ 600 and 912 Å. However, sources with a sufficiently hard intrinsic extreme-UV continuum will become bright again at shorter EUV wavelengths. Such objects will have very peculiar colors in broadband optical/UV imagery, and the UV-blue bandpass for which WFC3 is optimized is ideally suited to search for these. Such techniques might be able to identify the first generation of active galactic nuclei.

5. Near-Infrared Science

The WFC3 infrared channel has unique and powerful capabilities in the 0.8-1.7 μm spectral region. HST, even with a relatively warm optical system, offers four key advantages for near IR imaging over much larger ground-based facilities:

- continuous coverage of the 0.8-1.7 μm wavelength range, unaffected by the atmospheric water vapor absorption which mutilates ground-based data;
- a reduction by nearly 3 orders of magnitude in the sky background emission shortwards of 1.7 μm (due primarily to atmospheric OH bands);
- the ability to have stable, uniform, near diffraction-limited imaging over a large field of view (135 × 135 arcsec with WFC3);
- stable and accurate photometry over a large field of view compared to the small isoplanatic patch and variable point spread function available to ground-based adaptive optics (AO) systems.

Such a potent combination of performance characteristics is impossible to achieve from the ground and makes the near-IR capabilities of WFC3 compelling.

In the design of WFC3/IR it was decided not to cover wavelengths out to the 2.5 μm cutoff of NICMOS. This compromise allows the WFC3 near-IR detector to be cooled simply by thermo-electric coolers, rather than by expendable cryogen or a mechanical cooler. The fact that WFC3-IR does not extend to the K band (2.2 μm) is not a serious limitation, since the HST Optical Telescope Assembly (OTA) itself generates a significant background at K, while adaptive-optics systems on large ground-based telescopes optimized for IR performance will become very competitive in the K band during this decade. On the other hand, the reduction in the H band (1.6 μm) sky background in space renders HST near-IR imagers more sensitive than similar instruments on 8-meter class ground-based telescopes, even with sophisticated adaptive-optics systems. Thanks to the use of more modern detectors, WFC3 improves on the discovery efficiency of NICMOS by more than a factor of 15. Below we have singled out a few examples from the many programs that are made possible by WFC3/IR.